Models of Cosmic Acceleration: Challenges and Exciting Directions

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UC Davis

COSMO 02

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Faculty Position
High Energy Theoretical Physicist
Department of Physics
University of California, Davis

The Department of Physics at the University of California at Davis invites applications for a faculty position in theoretical high energy physics. **Appointment at any level is possible depending upon qualifications and experience.** The successful candidate will be the first of three planned new appointments directed toward pursuit of exciting new ideas and challenges associated with the interface between formal theory and phenomenology.

This position is open until filled; but to assure full consideration, applications should be received no later than January 2, 2003. This targeted starting date for appointment is July 1, 2003.

I) Challenges for models of cosmic acceleration

I.1 The cosmological constant problem / links to fundamental gravity.

I.2 The "why this/why now" problems

I.3 Quantum corrections/long range forces

II) Exciting Directions

II.1 The quantum physics of Λ

II.2 Dark energy/quintessence, Stage I (adventures)

II.3 Dark energy/quintessence, Stage II (getting serious)

III) Conclusions

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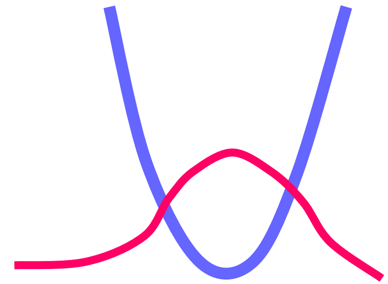
As far as we can tell so far, the cosmic acceleration might be the result of

$$\boxed{\Lambda \approx 10^{-120} M_P^4 \approx \left(10^{-3} eV\right)^4}$$

Greatest unsolved problem in physics:

Why is $\Lambda \leq 10^{-120} \Lambda_{QFT}$



Λ = 10^{120}

Vacuum Fluctuations

$\Lambda \equiv 0$?

Challenges:

- $\Lambda \equiv 0$ dream may not work
- A more mature fundamental theory of gravity could overturn ideas about the origins of acceleration
- Huge potential for observations to impact fundamental theories

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Why this?

➔ Where does this strange parameter come from?

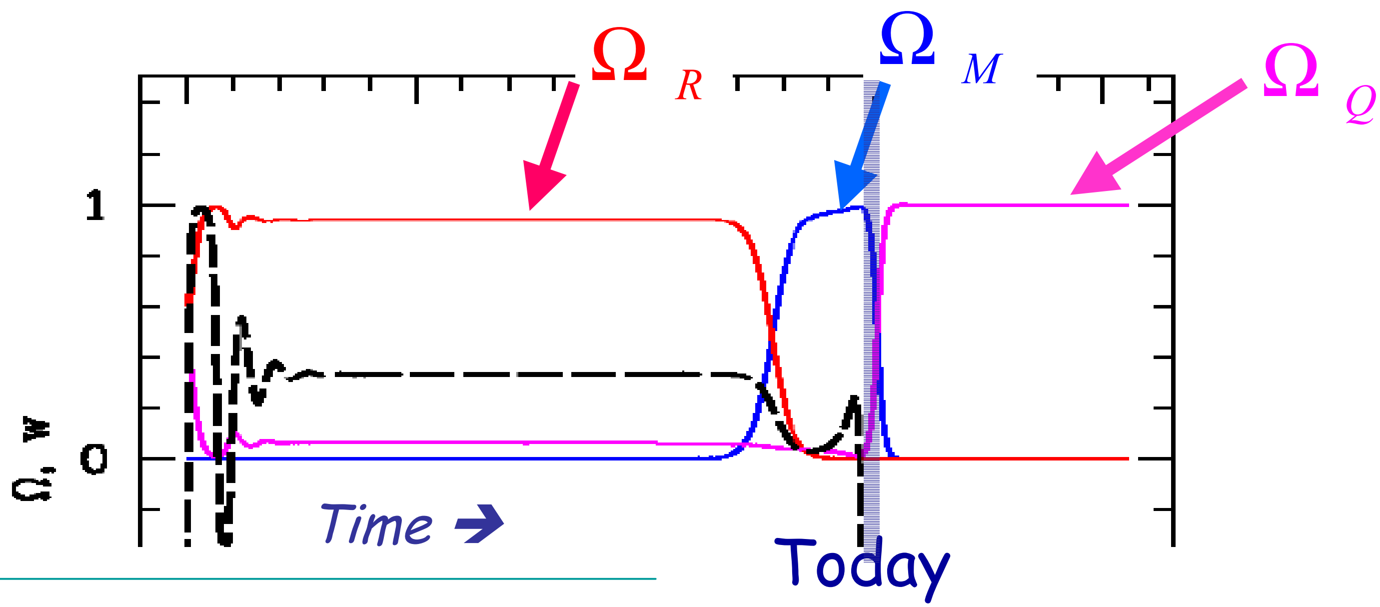
$$\boxed{\Lambda \approx 10^{-120} M_P^4 \approx \left(10^{-3} eV\right)^4}$$

Why now?

➔ If the source of acceleration is some dynamical matter ("quintessence"), then it has to acquire the value

$$\boxed{\Lambda_{eff} \approx 10^{-120} M_P^4 \approx \left(10^{-3} eV\right)^4}$$

today (t=14.5 Gyr). (not some other time)



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➔If the acceleration is produce by a scalar field (quintessence):

i) The quintessence field must have a mass

$$\boxed{m_Q \le 10^{-32} eV}$$

How can this value stay safe from quantum corrections?

➔ If the acceleration is produce by a scalar field (quintessence):

ii) If such a small mass is preserved, there is a new long range force mediated by the quintessence field.

How can 5th force bounds be evaded?

(Carroll)

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i) The entropy bound:

- If there really is a $\Lambda \neq 0$, the late-time asymptotic state of the universe will have a horizon with area:

$$\boxed{A}$$

- This implies a Hawking-Beckenstein type upper bound on the entropy:

$$\boxed{\frac{A}{4G} = S_{MAX} \geq S = \text{"}\ln N\text{"}}$$

- Are we then compelled to only consider only models of physics with a finite dimensional Hilbert space? (Excludes field theory, M-theory, SHO, etc.)

T. Banks & W. Fischler

ii) Other constraints on fundamental theories with Λ :

- Do scattering states exist? etc

iii) Causal set theory of gravity:

$$\left\langle {\rho_\Lambda}^2 \right\rangle \approx \left\langle {\rho_{TOT}}^2 \right\rangle$$

a prediction of causal set theory?!

(Ahmed et al. Sep 2002)

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➔ Inflation has taught us how to accelerate the universe with a scalar field… why not try again?

$$\boxed{V = M^4\left[\cos(\varphi / f) + 1\right]}$$

With $f \approx 10^{18}\,GeV$, $M \approx 10^{-3}\,eV$

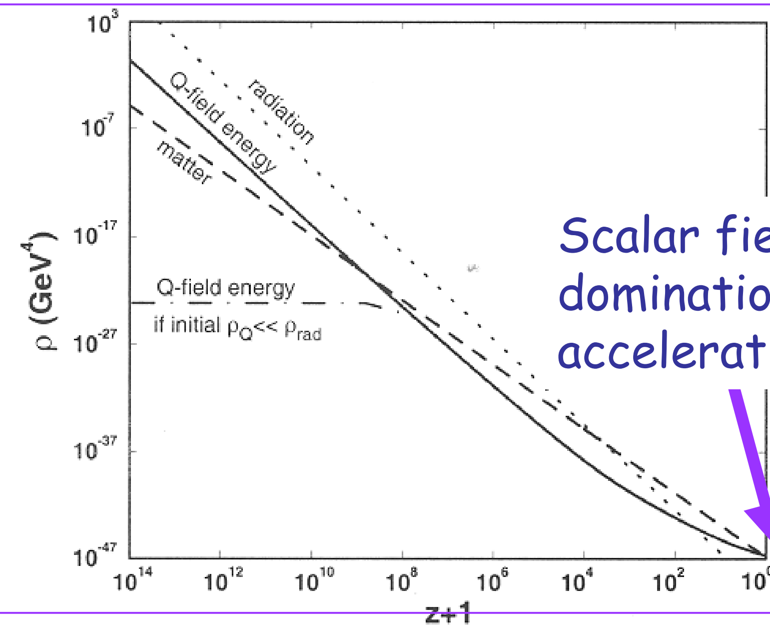
PNGB: Frieman, Hill, Stebbins, & Waga 1995

$$\boxed{V = M^{4+\alpha}\varphi^{-\alpha}}$$

Zlatev, Wang & Steinhardt 1998

$$\boxed{V = M^4\left[e^{M_P/\varphi} - 1\right]}$$

$M = 1\ meV - 1\,GeV$



Scalar field domination/ acceleration

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N.B Resurrect the $\Lambda \equiv 0$ dream

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Zlatev, Wang & Steinhardt 1998

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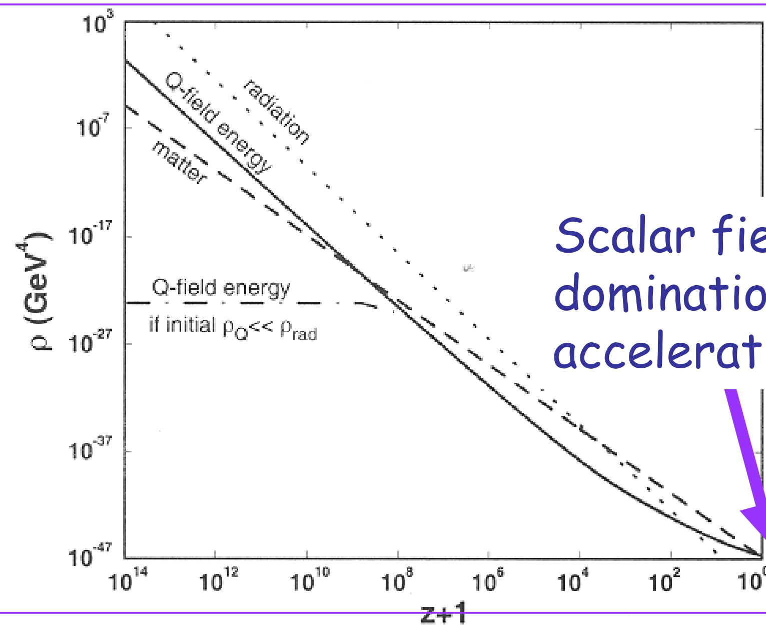
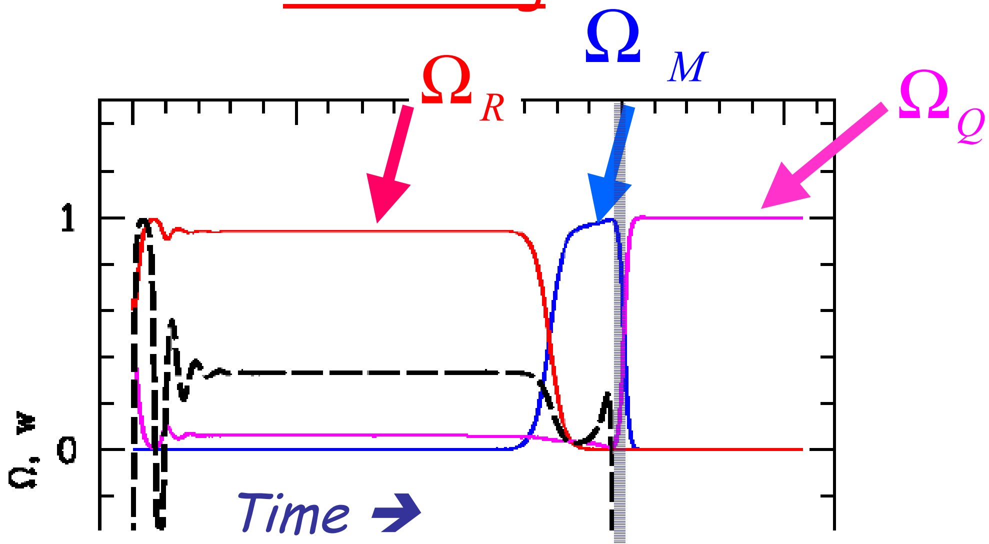


Scalar field domination/ acceleration

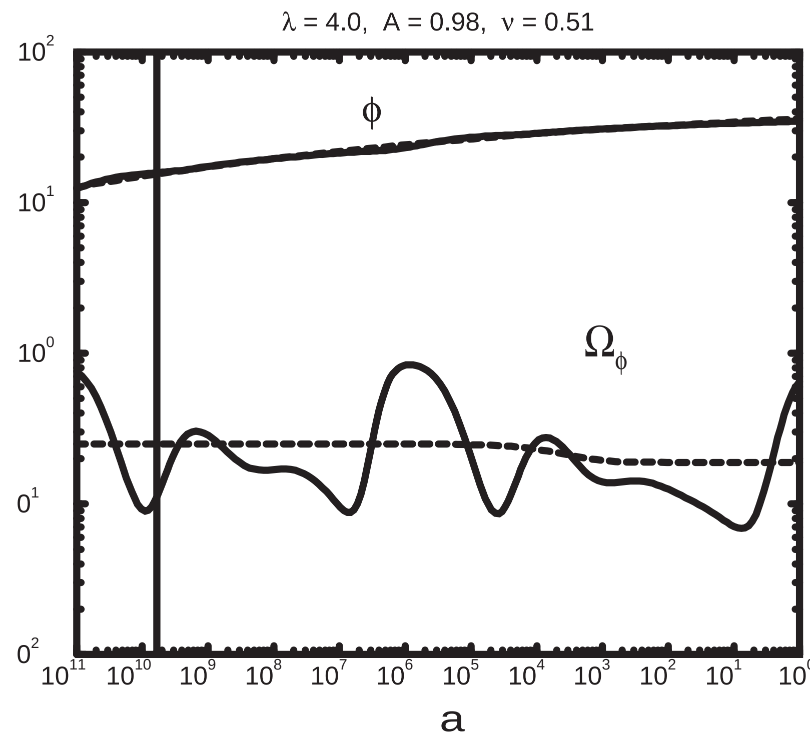
➔ Some more scalar field models of dark energy:

<u>Shadowing</u>



Albrecht & Skordis 1999

<u>Oscillating</u>



Dodelson Kaplinghat & Stewart 2000

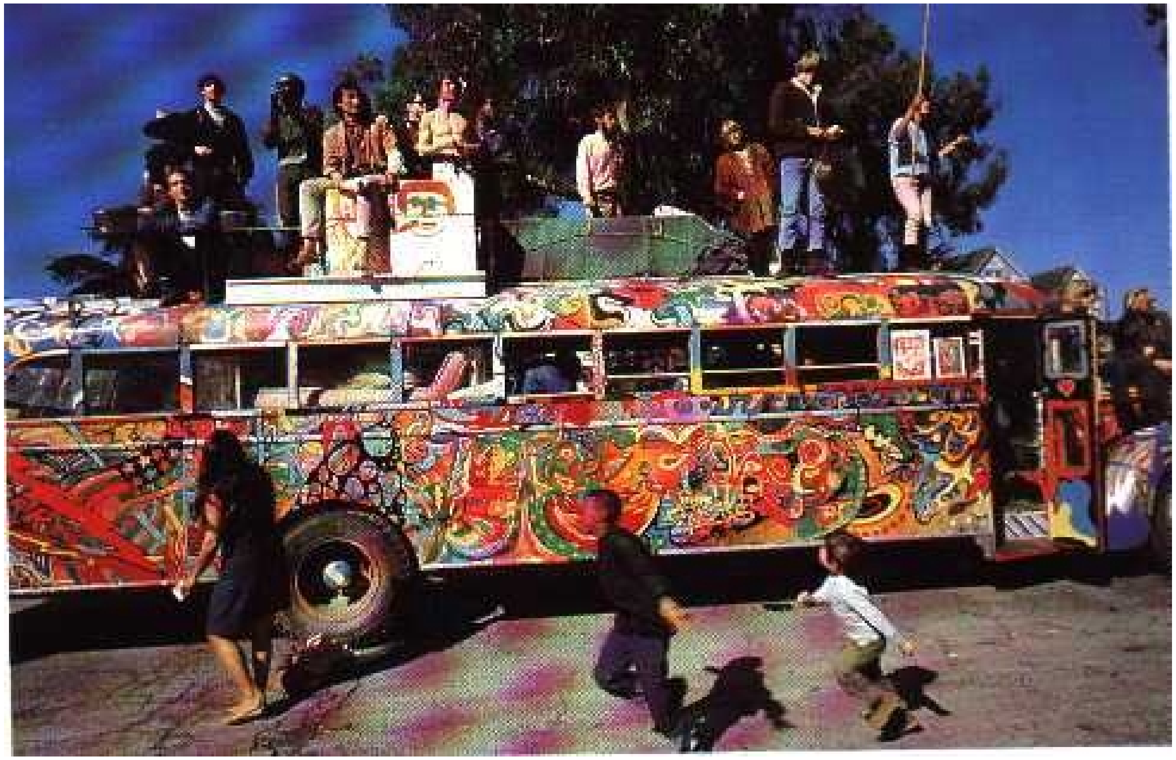
There are *many* other examples

→ A note about the "why this/now" problem:

- Essentially all existing quintessence models "solve" it by relating $\Omega_{\varphi}(t)$ to parameters in the quintessence equations
- Attractor behavior gets rid of initial conditions dependence
- How compelling this "solution" is depends on how convinced you are that nature has chosen those parameters.

➔ A note about Quantum corrections/long range forces:

- Almost all models of dynamical dark energy/quintessence completely ignore these issues. ➔ "adventures"



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Stage II: Take quantum corrections/long range forces seriously

*PNGB: Frieman, Hill, Stebbins, & Waga 1995

* Extra dimensions

A.A, Burgess, Ravndal 2001

* Supergravity Kalosh et al. 2002 (?)

• Challenging particle physics issues

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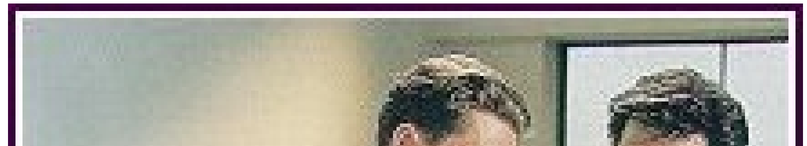

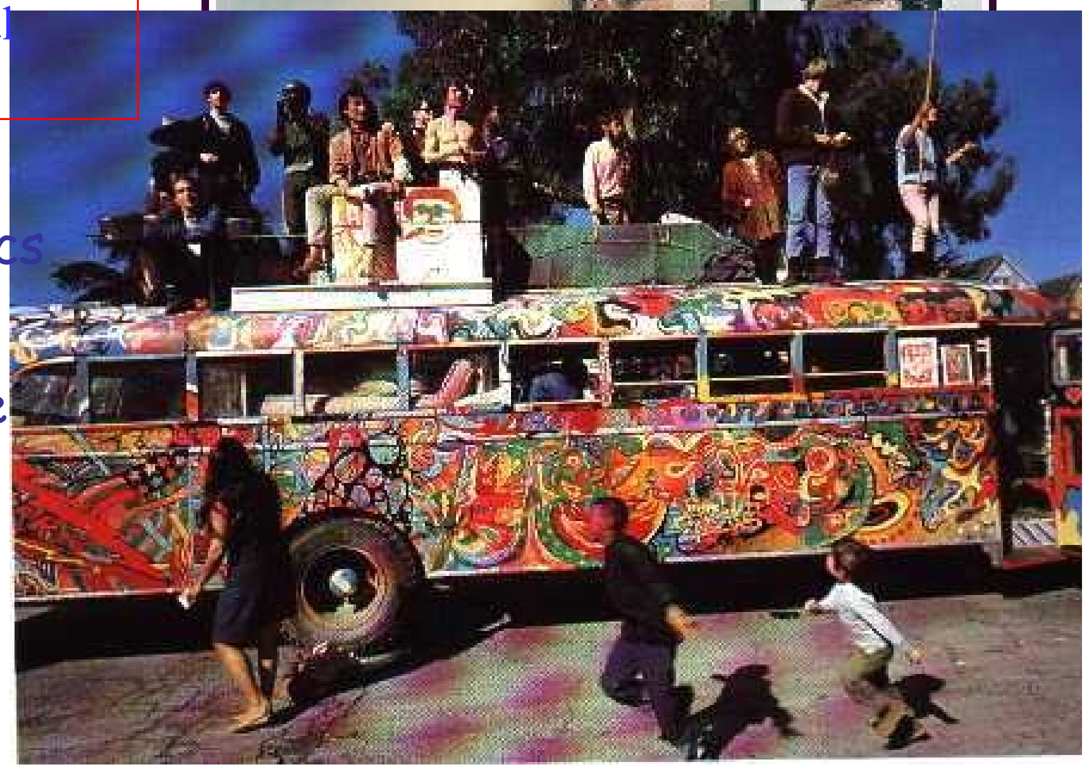

- Challenging particle physics issues

➔ Also: Risky because more radical developments could invalidate these efforts

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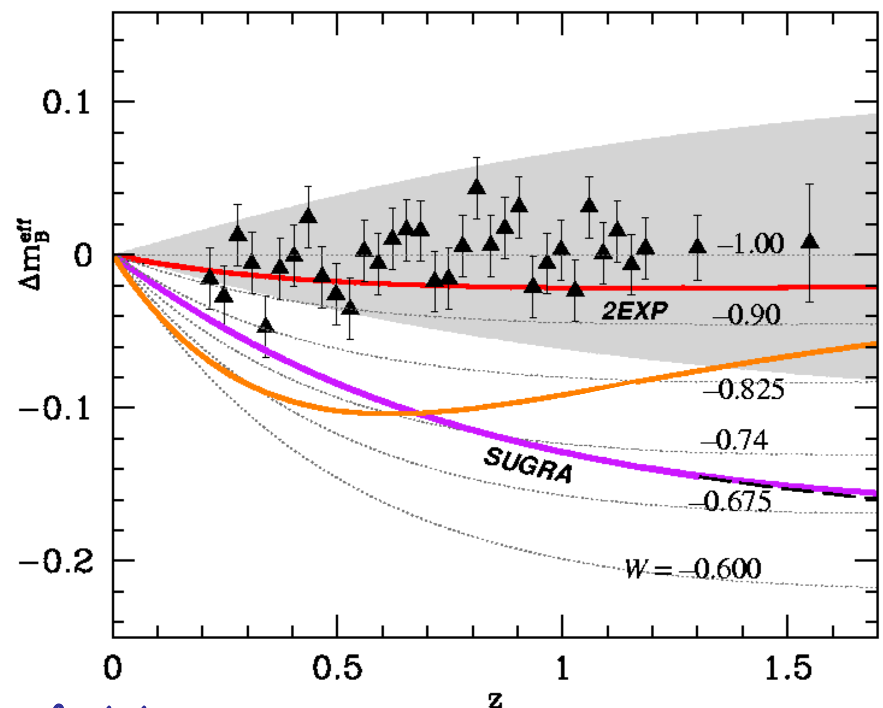
Modeling cosmic acceleration leads to:

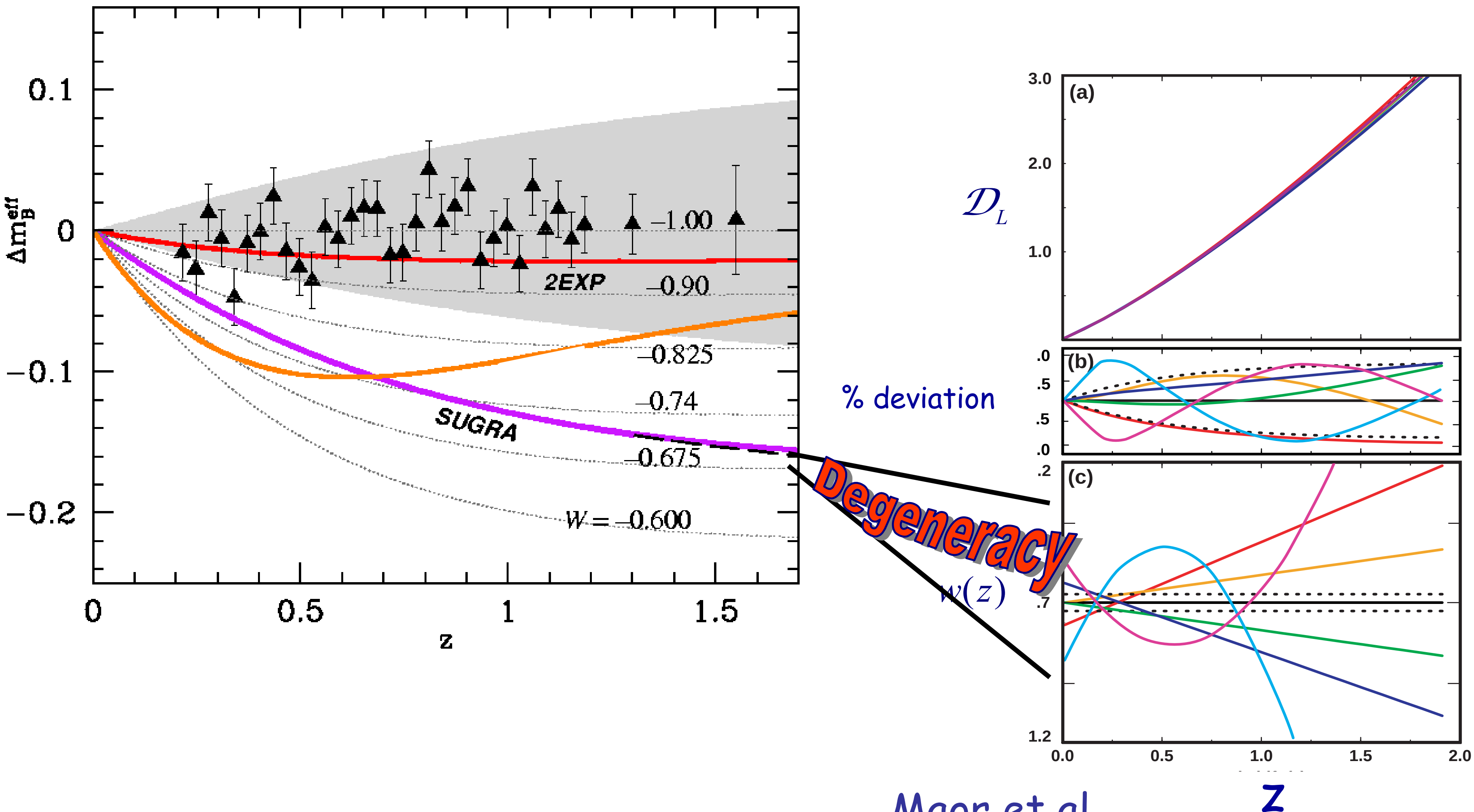
➔ Exciting challenges and new directions, many of which are connected with very fundamental questions.

➔ Real opportunity for dramatic observational advances



Weller & AA

NB: Don't be afraid of degeneracies!! Data can still distinguish among many interesting models



Maor et al.